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13. ABSTRACT (*Maximum 200 words*)

Work by Prof. Smith and his collaborators is summarized here.

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Distortion-Free X-Ray Mask Technology

Final Technical Report
for the period
June 12, 1990 to June 10, 1991

by
Research Laboratory of Electronics
Massachusetts Institute of Technology
Cambridge, MA 02139

Principal Investigator

Prof. Henry I. Smith
Dept. of Electrical Engineering and Computer Science
Massachusetts Institute of Technology
August 12, 1991

Objective:

The objective of this research project is to develop a closed-loop, feedback-controlled, robust system for reliably achieving zero stress in tungsten (W) films sputtered onto various x-ray mask membranes, and to transfer the technology to the National X-ray mask shop. Our system for controlling stress in sputtered W films is based on the measurement of resonant frequency. Since resonant frequency depends on both the thickness and the stress of the W films, if the thickness is known, the stress is easily calculated from

$$V_{res} = A \left[\frac{B + \sigma_w t_w}{C + Dt_w}\right]^{1/2}$$

where A, B, C and D are constants, known in advance, σ_w is the tungsten stress and t_w is the W thickness.

Progress:

1. In-Situ Monitoring of W Stress

We have interacted with ATT Bell Labs in an effort to transfer our technology of using membrane resonant frequency to monitor stress in sputtered W. They have set up a circuit that continuously tracks resonant frequency; an approach that appears to be superior to our system which sweeps over a band. Based on their criticism that our initial results on stress control involved very wide swings in stress, we carried out a series of experiments sputtering W on SiN_x membranes with the sputtering pressure held fixed during deposition. Resonant frequency was monitored, but no effort made to follow a predetermined curve. The results are shown in Fig. 1. These results make it clear that one can easily distinguish between the functional dependence that will yield a stress below 10^8 dynes/cm^2 and that

which will yield higher stresses. We find that we can consistently get zero stress W simply by setting the sputtering parameters and leaving them fixed during the deposition.

2. <u>In-Plane Distortion Measurements</u>

We have continued our efforts to verify that zero out-of-plane distortion insures that there is zero in-plane distortion. To this end we are developing a moiré technique that involves first creating a coherent, distortion-free holographically-generated relief grid in the mask membrane. The membrane is then patterned with W and distortion measured via the moiré effect when another holographic exposure is done on top of the grid. This project ran into some difficulties: the SiN_x membranes (1 μm thick) became overheated during RIE. We will use a thick layer of water soluble polyvinyl alcohol (PVA) on the back of the membrane to prevent this problem. We expect results soon.

3. <u>X-ray Mask Membrane Testing</u>

Figure 2 shows the results of our optical technique for nondestructively determining membrane thickness and index of refraction.

4. <u>Diffraction Analysis</u>

We have completed an exact calculation, based on Maxwell's equations, of the diffraction from 0.1 μm features. We used a Cray 2 computer and the so-called method of moments (MoM). The results show that Kirchhoff boundary conditions are inapplicable in X-ray lithography diffraction calculations. This is shown in Fig. 3.

5. <u>E-Beam Generation of X-ray Masks</u>

Working with the NRL e-beam lithography system we have worked out procedures for exposing 0.1 μm patterns on X-ray mask membranes, and

plating them here at MIT. Results are shown in Fig. 4. We hope to expand this collaboration in the future.

6. Reactive Ion Etching of W

We have developed methods of reactive-ion etching W films with good CD control. However, we also discovered that membrane heating is a serious problem. We will use back-side PVA or diffusion pump oil to circumvent this problem. However, we believe the optimal solution would be to provide back-side He cooling. We have proposed to build such a system.

7. Summary

In summary, we have passed all of our milestones except for perfecting methods of W RIE.

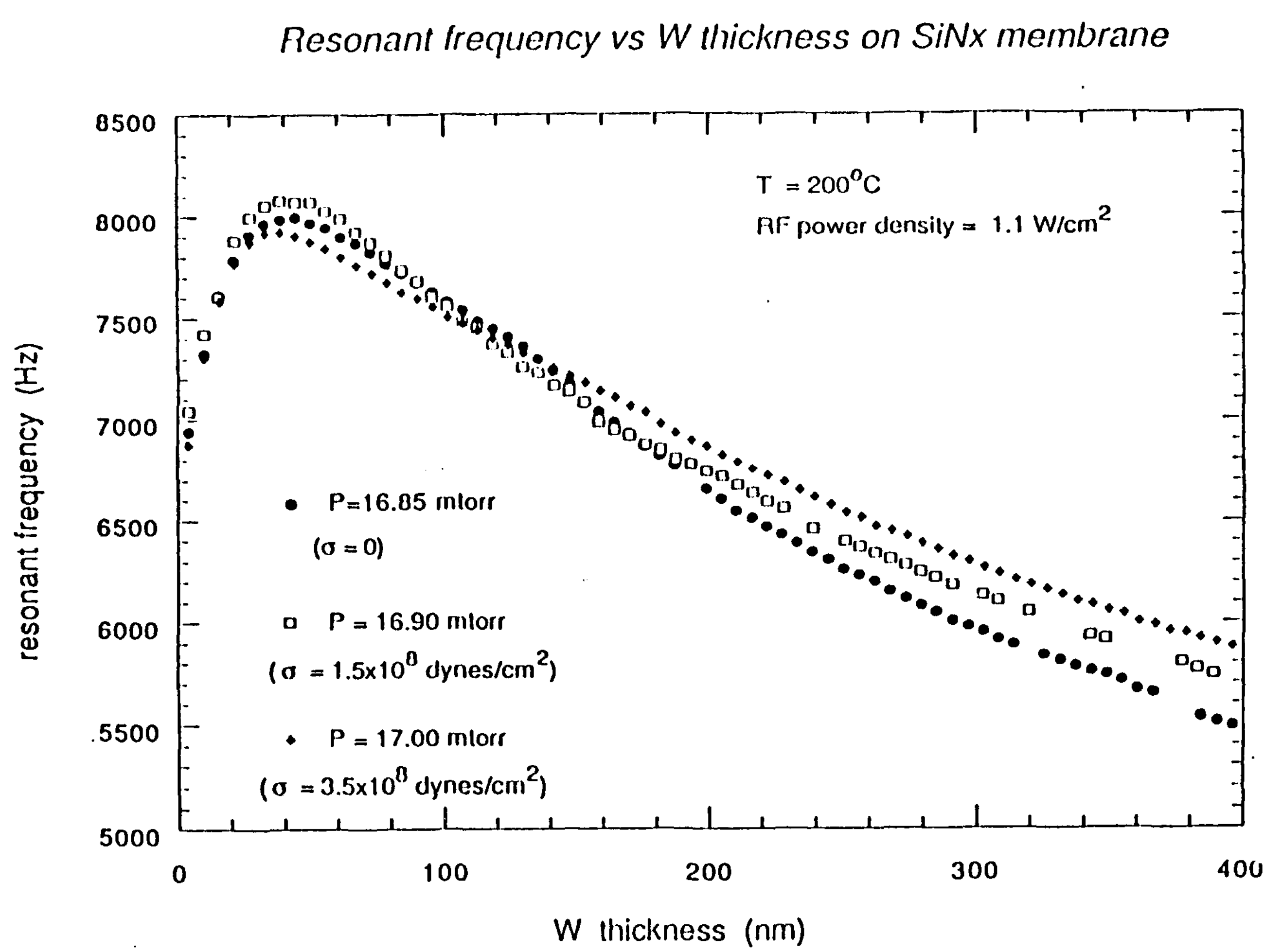


Fig. 1 Plots of measured resonant frequency, f_c, versus thickness of sputtered W for 3 values of pressure. The 3 membranes are low stress SiN_x, approximately 1.8 μm thick, with a mesa rim, but not a pyrex frame. The substrate platform was heated to 200°C. Additional transient temperature rise due to exposure to the plasma causes the initial peak in f_c. W stress was measured by Linnik interferometry at room temperature.

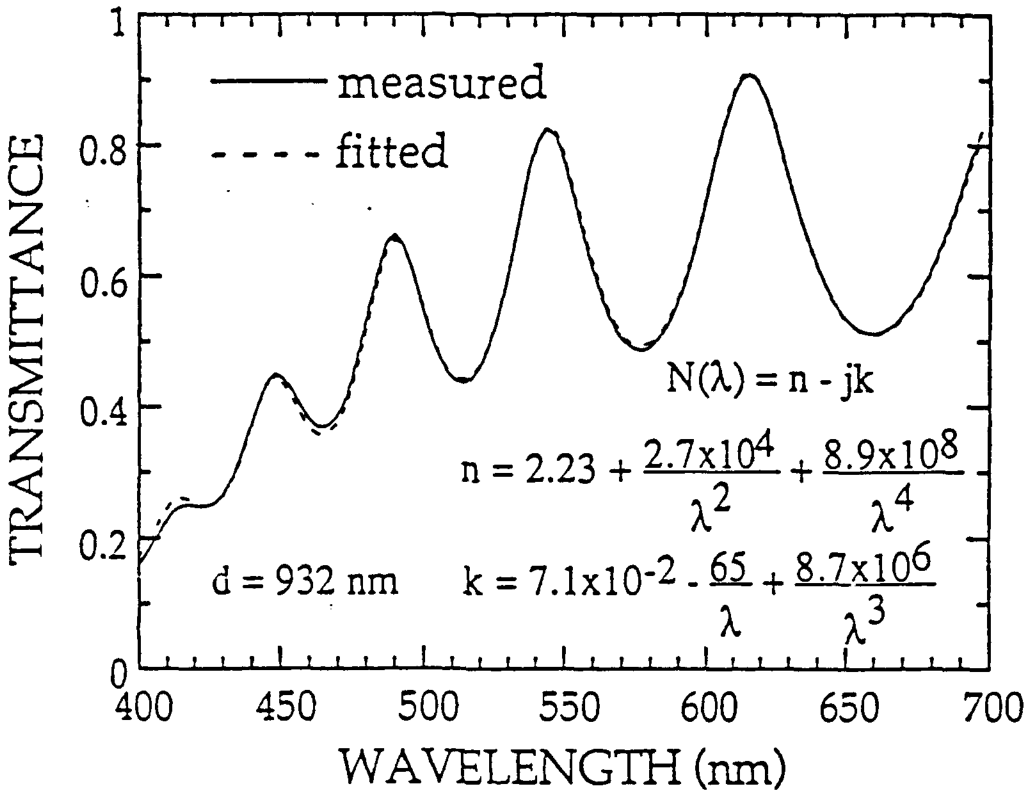
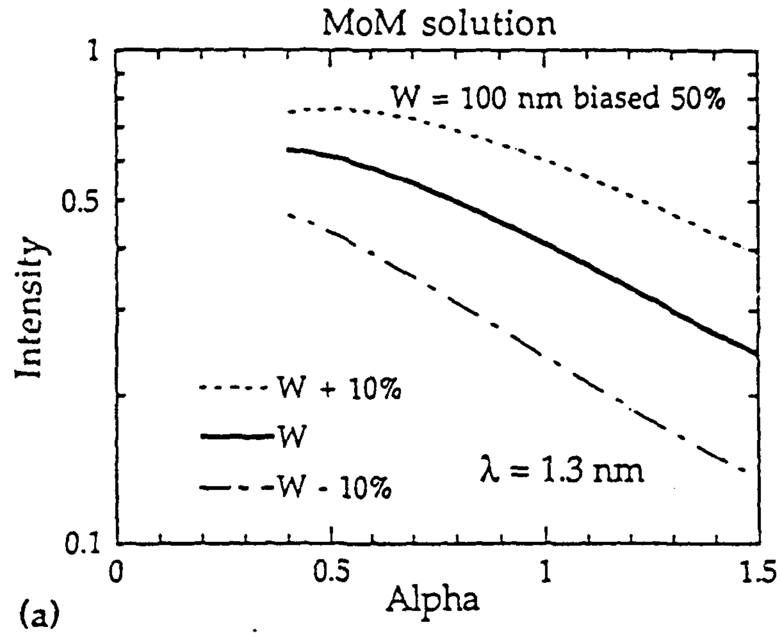
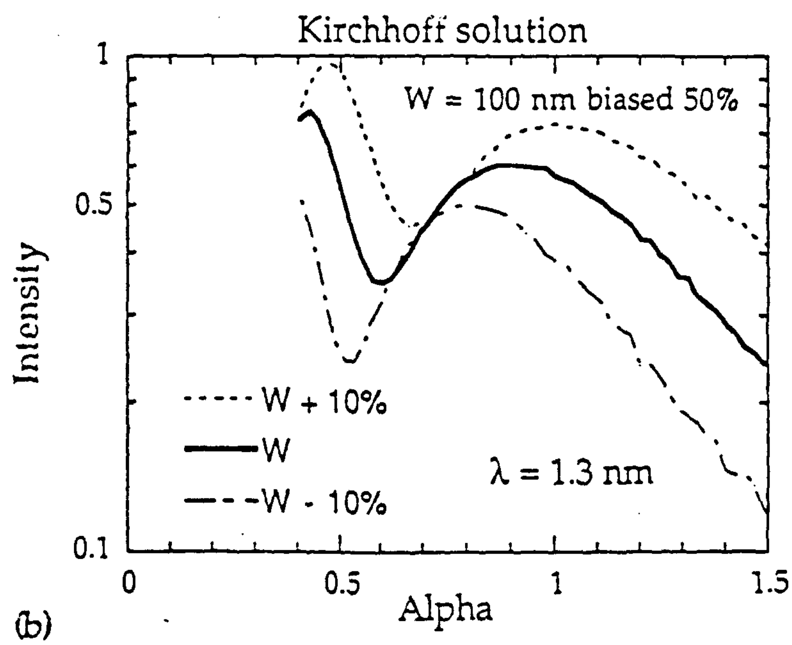


Fig. 2 Optical transmission curve for a silicon nitride membrane. The solid curve is the measured transmission as a function of wavelength. The dotted line is the result of a least-squares fit to the theoretical model. The fitting process determines, from a single measurement, both the membrane thickness, and the real and imaginary parts of the index of refraction as functions of wavelength.



(a)



(b)

Fig. 3 Exposure trees vs. α (dimensionless gap) for Case 2. (Gaps range from zero to 11.2 μm.) The line is biased 50% (150 nm resist line). (a) MoM solution, (b) Rayleigh-Sommerfeld-Kirchhoff approximation.

X-ray Mask of Quantum Point Contact
[Written by E-Beam Lithography at NRL]

Gate Pattern

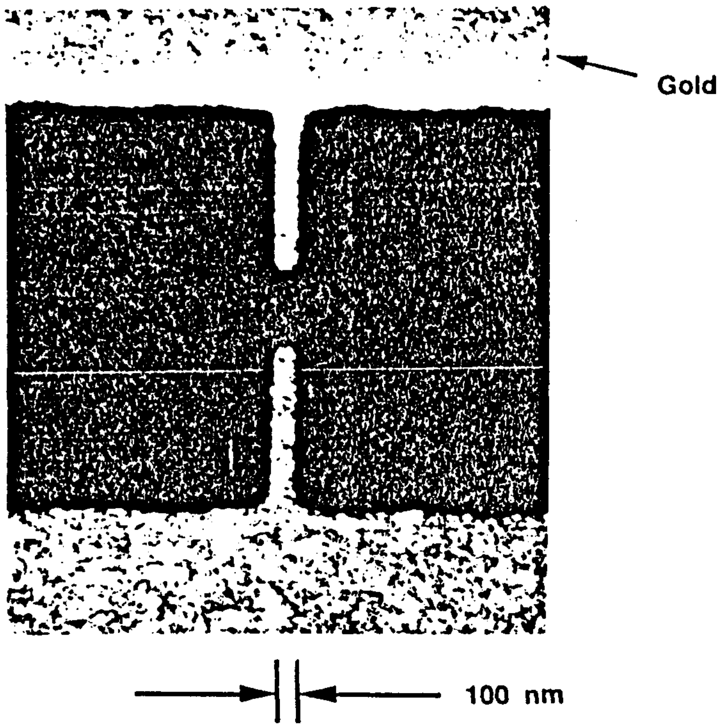
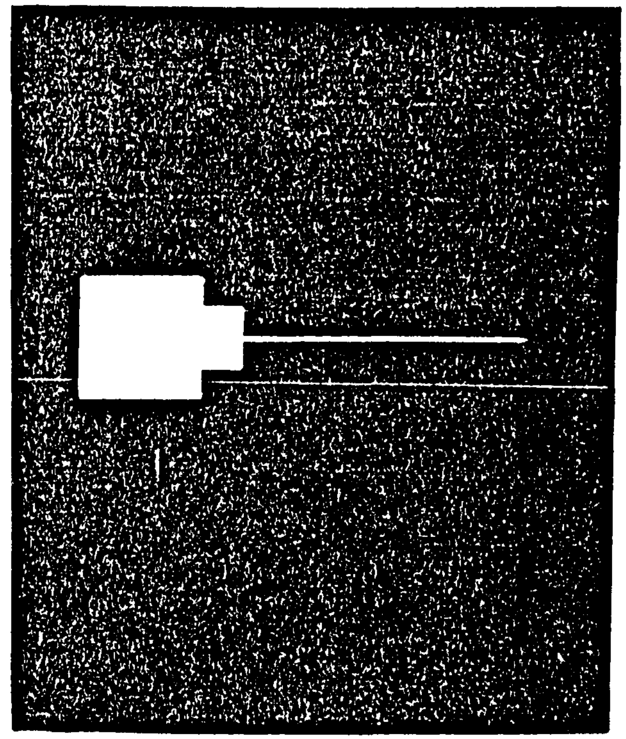


Fig. 4(a)

X-ray Mask for 0.1μm MOSFET
[Written by E-Beam Lithography at NRL]

Gate Pattern



Gate Length = 0.2 μm
Gate Width = 25 μm

Fig. 4(b)

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